Testing Interactions of Buoyancy, Multiphase Flow, and Geochemistry: Preliminary Results from the Frio II Test

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Setting for Frio test: refineries and and oilfield tubular laydown yards on the way to the site . Phot by SD Hovorka, BEG UT, JSG

Comparing Frio I and Frio II

Frio 1 October 2004 – January 2006

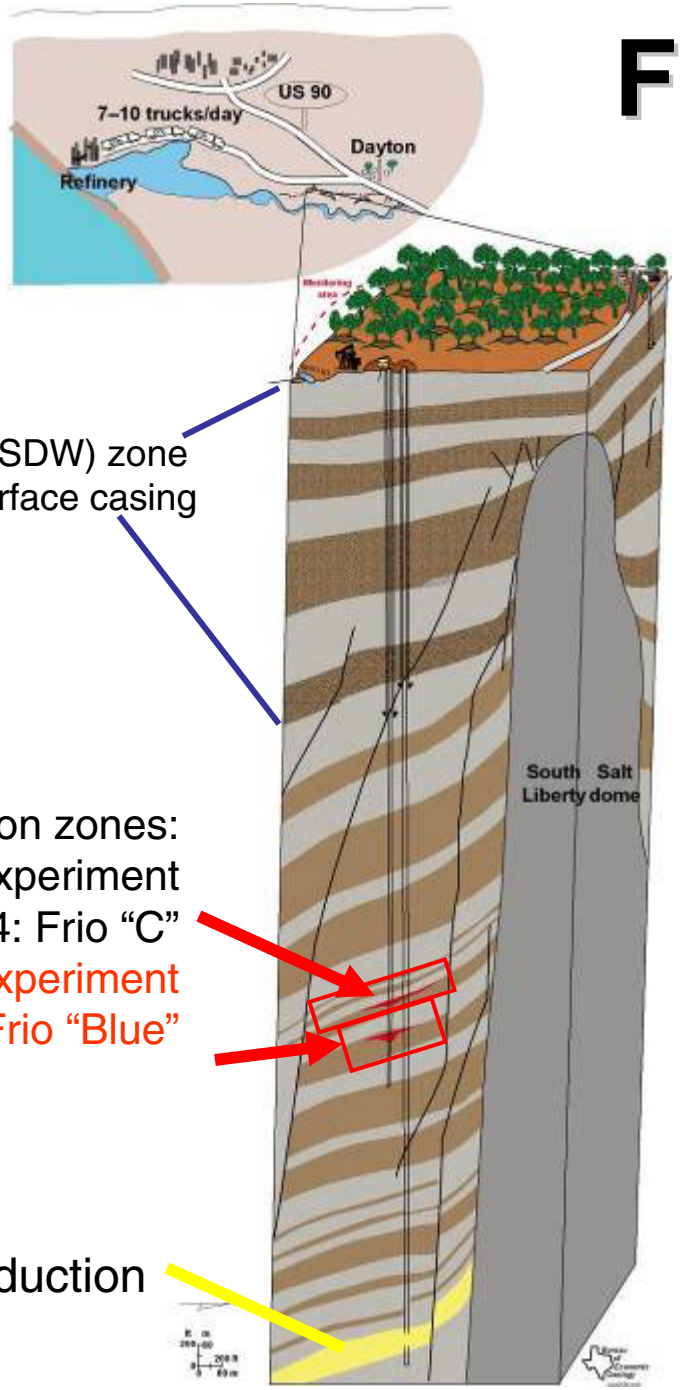
- (1) high-quality characterization prior to injection,
- (2) numerical modeling integrated with all phases of the project,
- (3) cross-comparison of multiple types of measurements,
- (4) use of wireline logs for monitoring plume movement,
- (5) data collection focused on selected azimuths,
- (6) above-zone monitoring for leakage

Frio 2 September 2006 – June 2007

- Storage permanence – quantifying residual saturation and dissolution
  - Post- injection monitoring under stable conditions TBD June 2007
  - Buoyancy in thick sand
    - Inject "deep": 6 feet perforation in base 32 ft thick sandstone
    - inject slowly: 50T/day x 5days
    - Rock-water reaction, tracer fractionation as a result of dissolution
    - Novel tool – tubing-conveyed seismic array

Frio Brine Pilot Site second test interval

Location
Near Houston
TX



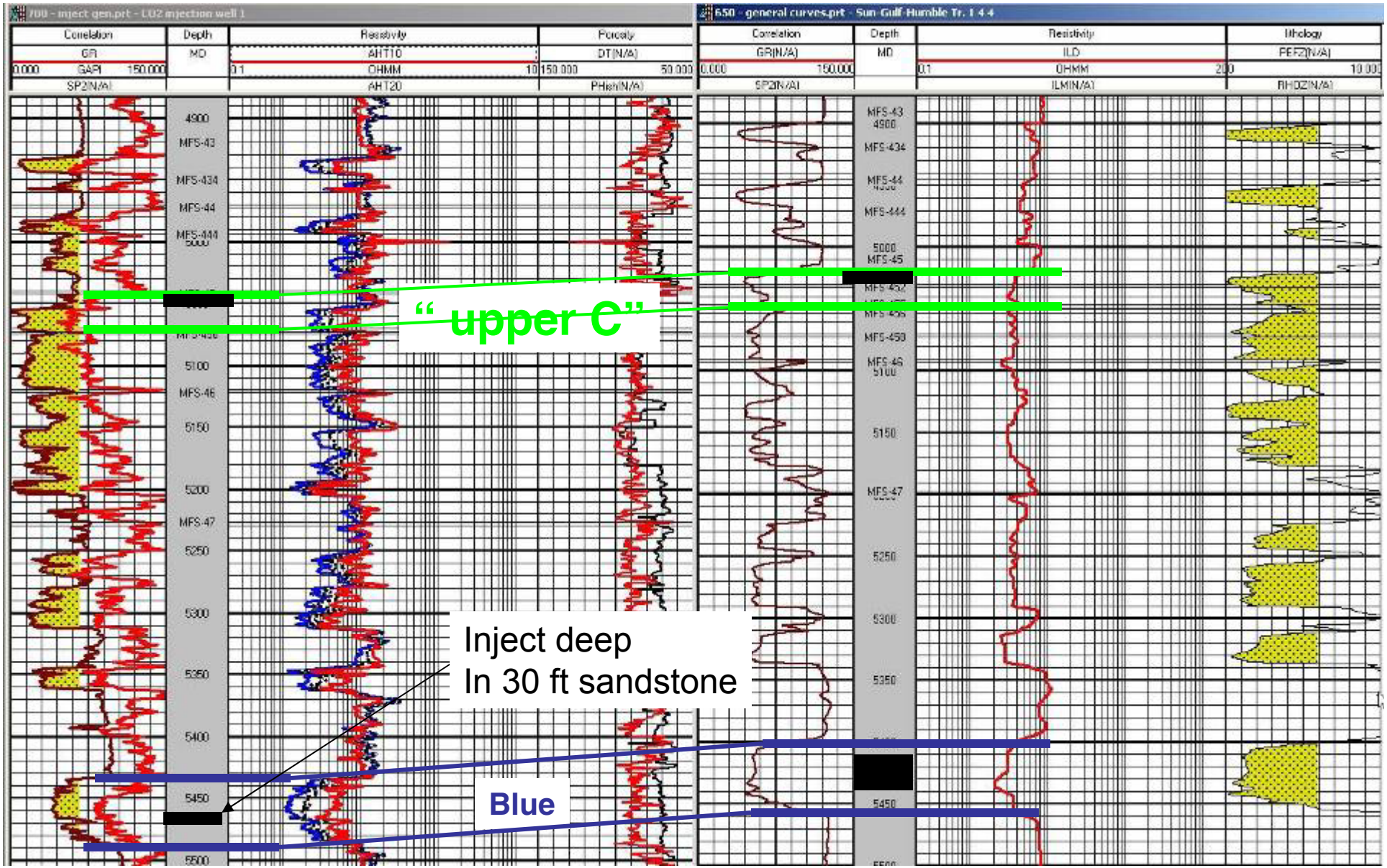
Fresh water (USDW) zone
protected by surface casing

Injection zones:
First experiment
2004: Frio "C"
Second experiment
2006 Frio "Blue"

Oil production

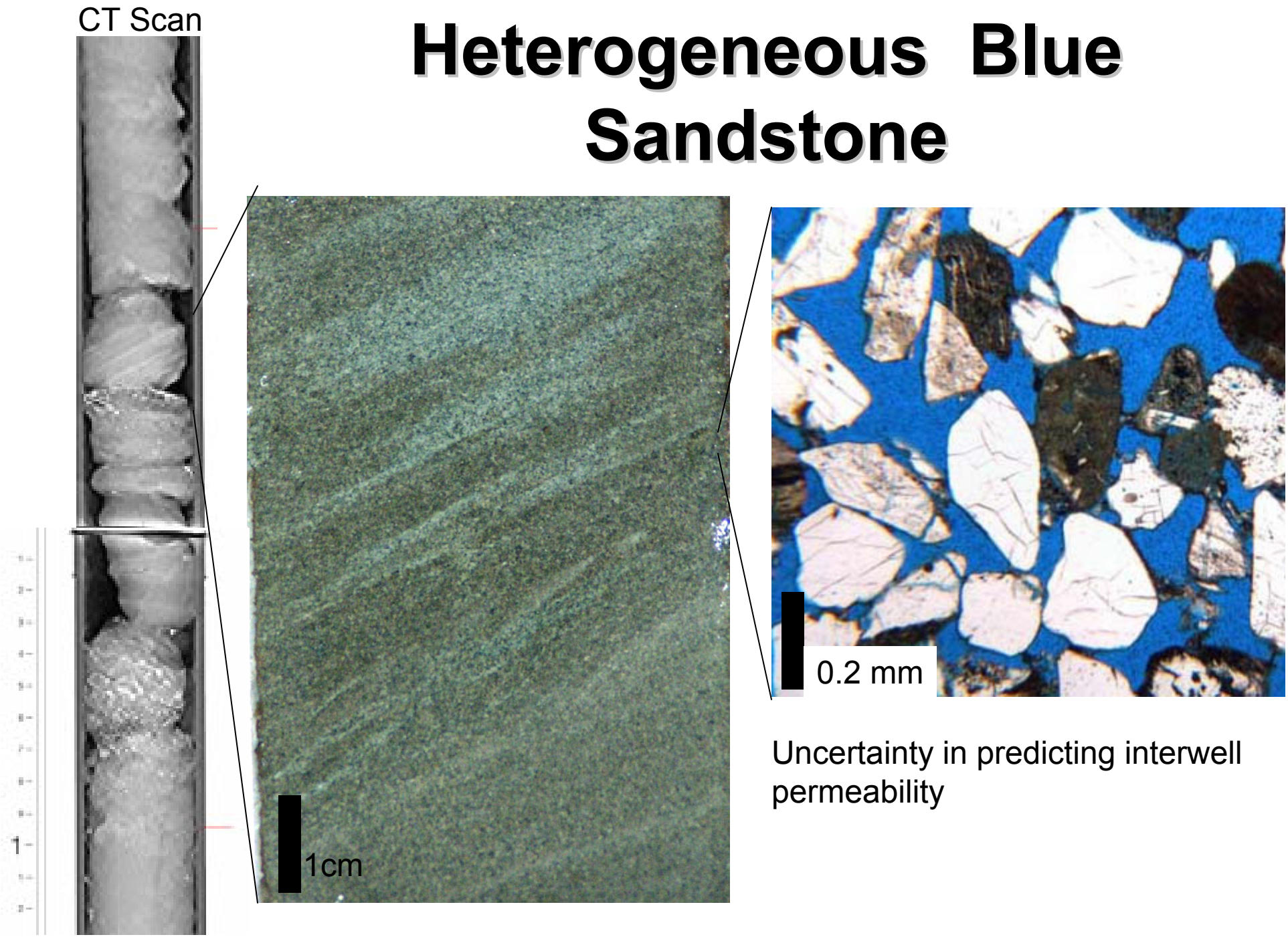
- Injection intervals: mineralogically complex Oligocene fluvial and reworked fluvial sandstones, porosity 24%, permeability 4.4 to 2.5 Darcys
- Steeply dipping 11 to 16 degrees
- Seals – numerous thick shales, small fault block
- Depth 1,500 and 1657 m
- Brine-rock system, no hydrocarbons
- 150 and 165 bar, 53 -60 degrees C, supercritical CO_2

Injection Well **Observation Well**



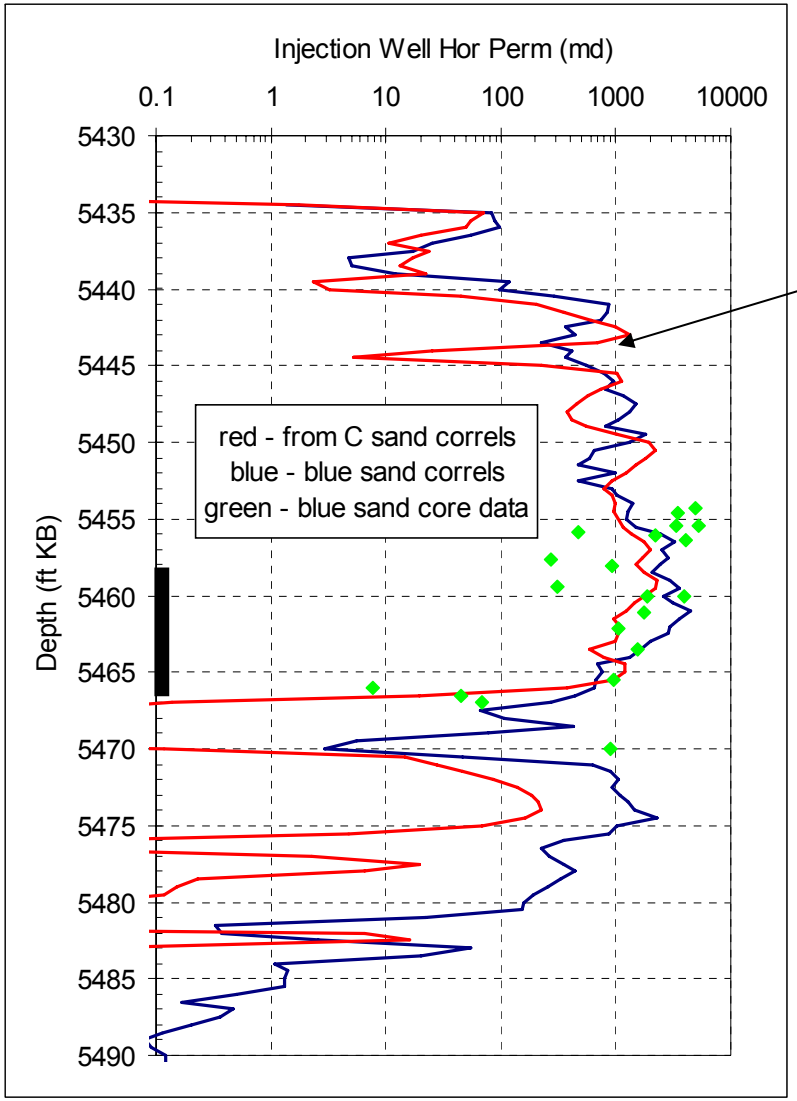
Mark Holtz, BEG

Heterogeneous Blue Sandstone



Uncertainty in predicting interwell permeability

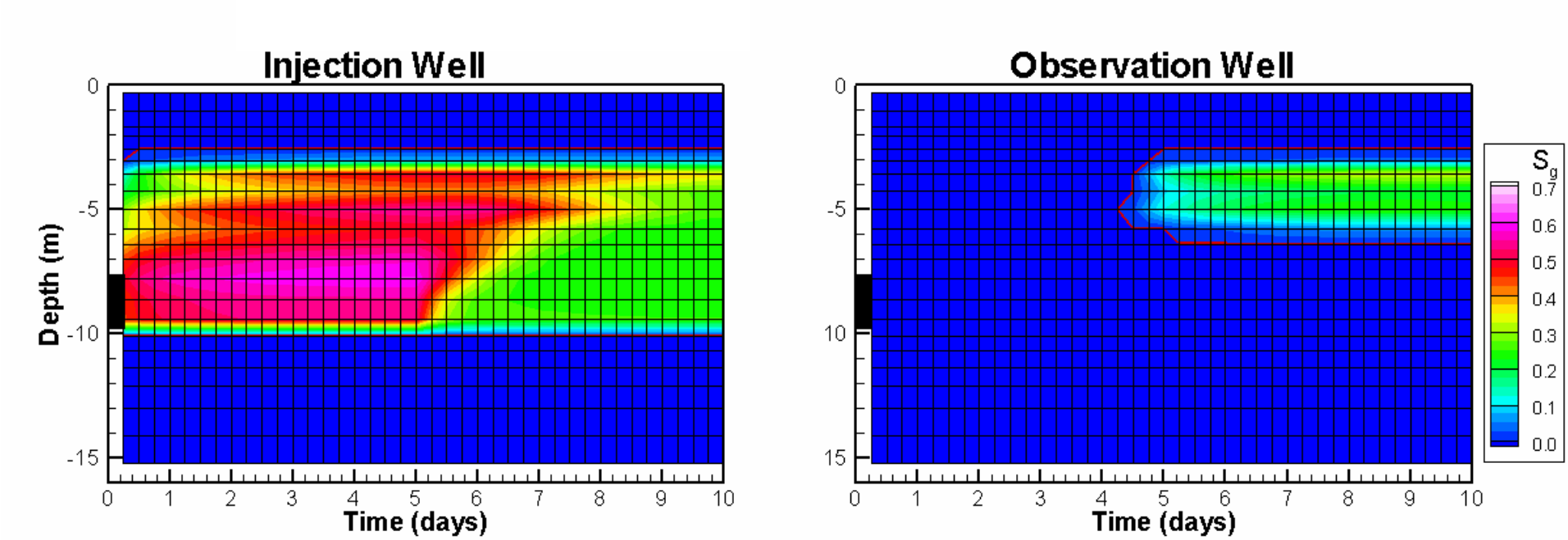
Uncertainly in Permeability Profiles



- **Red curve used for June 2006 model**
  - **Note low permeability at 5445 ft, modeled SCO_2 plume is trapped below it**
- **Blue curve used for pre-injection model Sept 2006)**
  - **Permeability at 5445 ft not low enough to stop CO_2 plume's upward movement**

Christine Doughty LBNL

Pre-Injection Modeled Saturation in Both Wells



Slow injection 100 T/day planned,
Injection low in thick high permeability sand
= Slow break though, good resolution on tracers and chemistry

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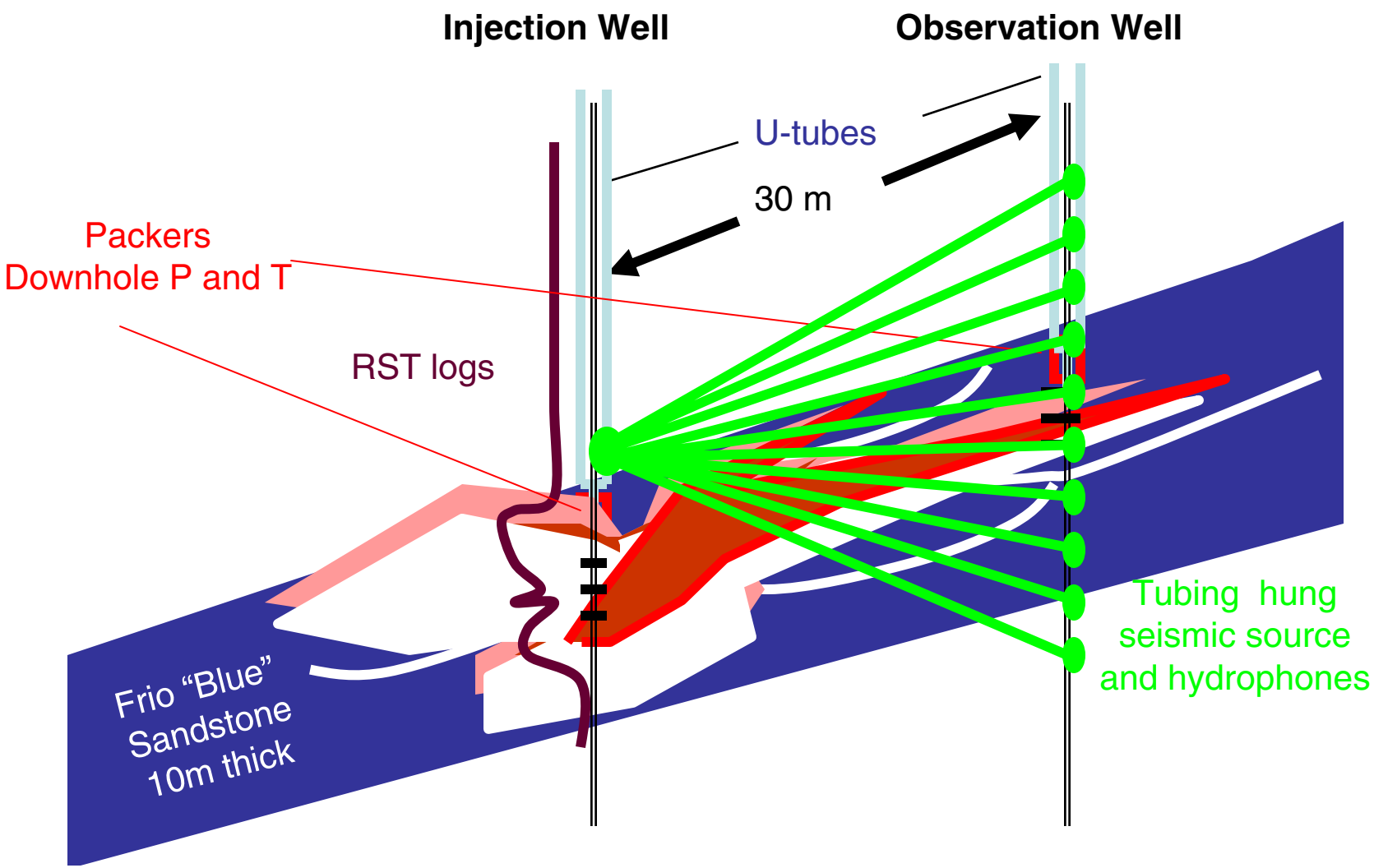
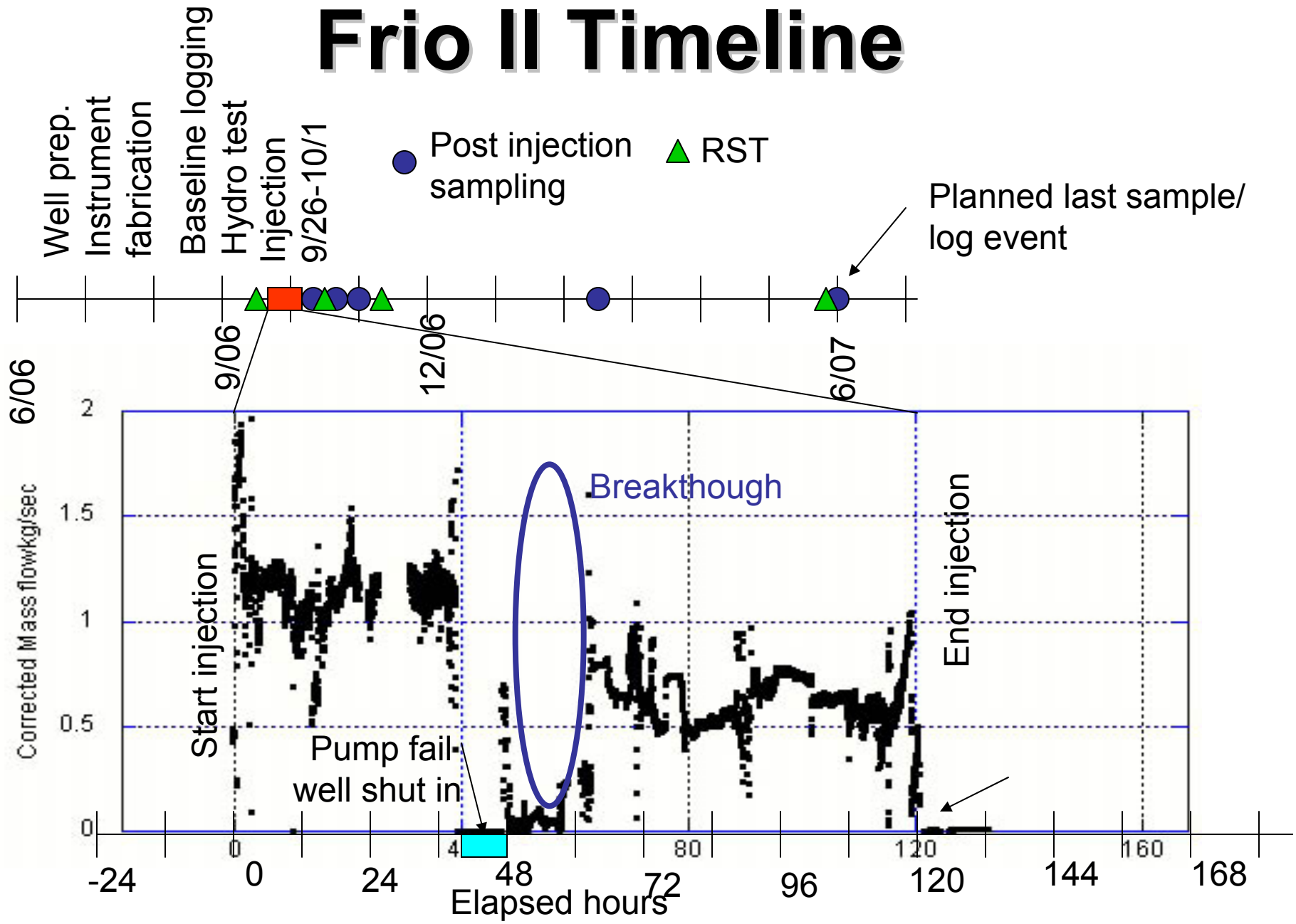
Frio 2 Monitoring Techniques Selected

- Injection zone characterization – core analysis, open and cased hole logs, single phase hydrologic testing
- RST logs: CO_2 saturation change with time – pressure and temperature change with depth
- Downhole Panex gages: pressure and temperature
- U-tubes – gas soluble tracer and aqueous transport and gas and aqueous chemistry
- Continuous Active Source Seismic Monitoring (CASSM) cross-well array

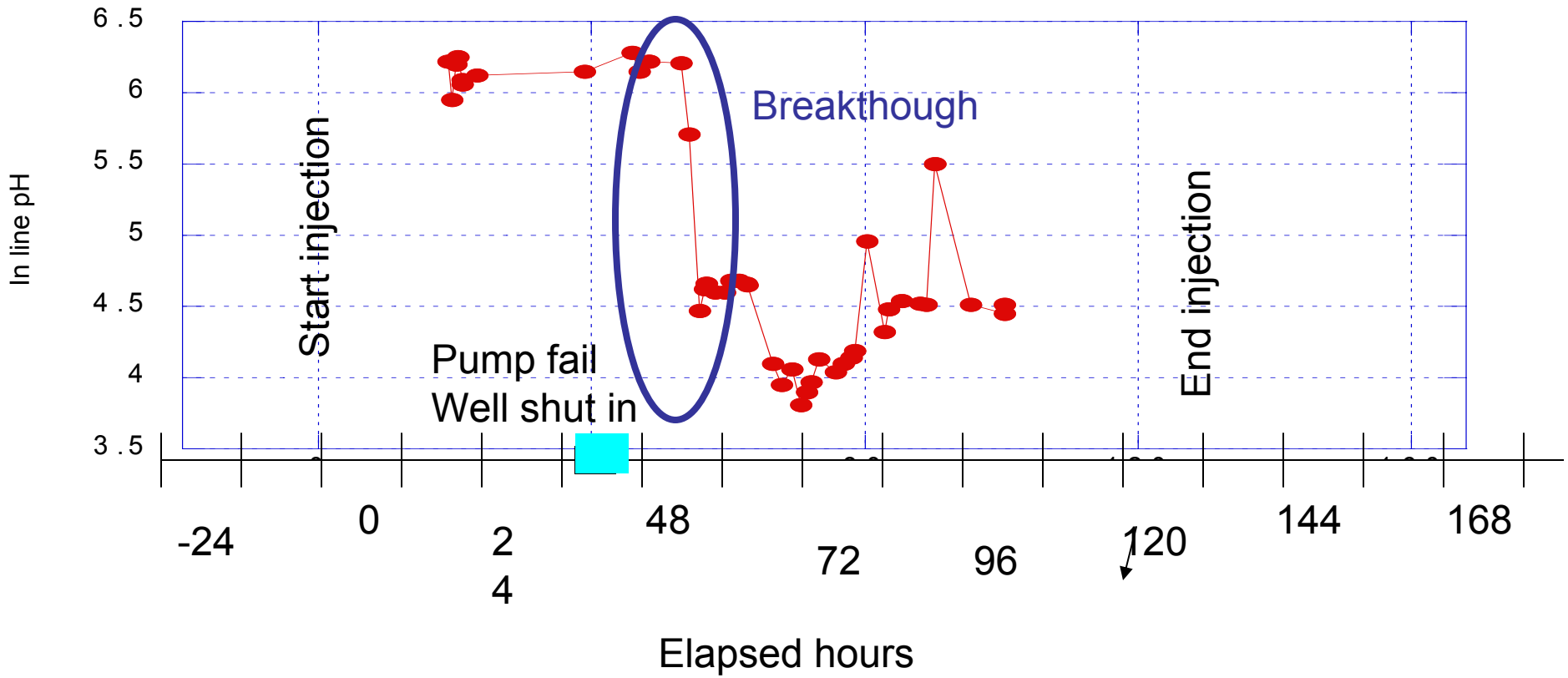
Monitoring Design Frio 2



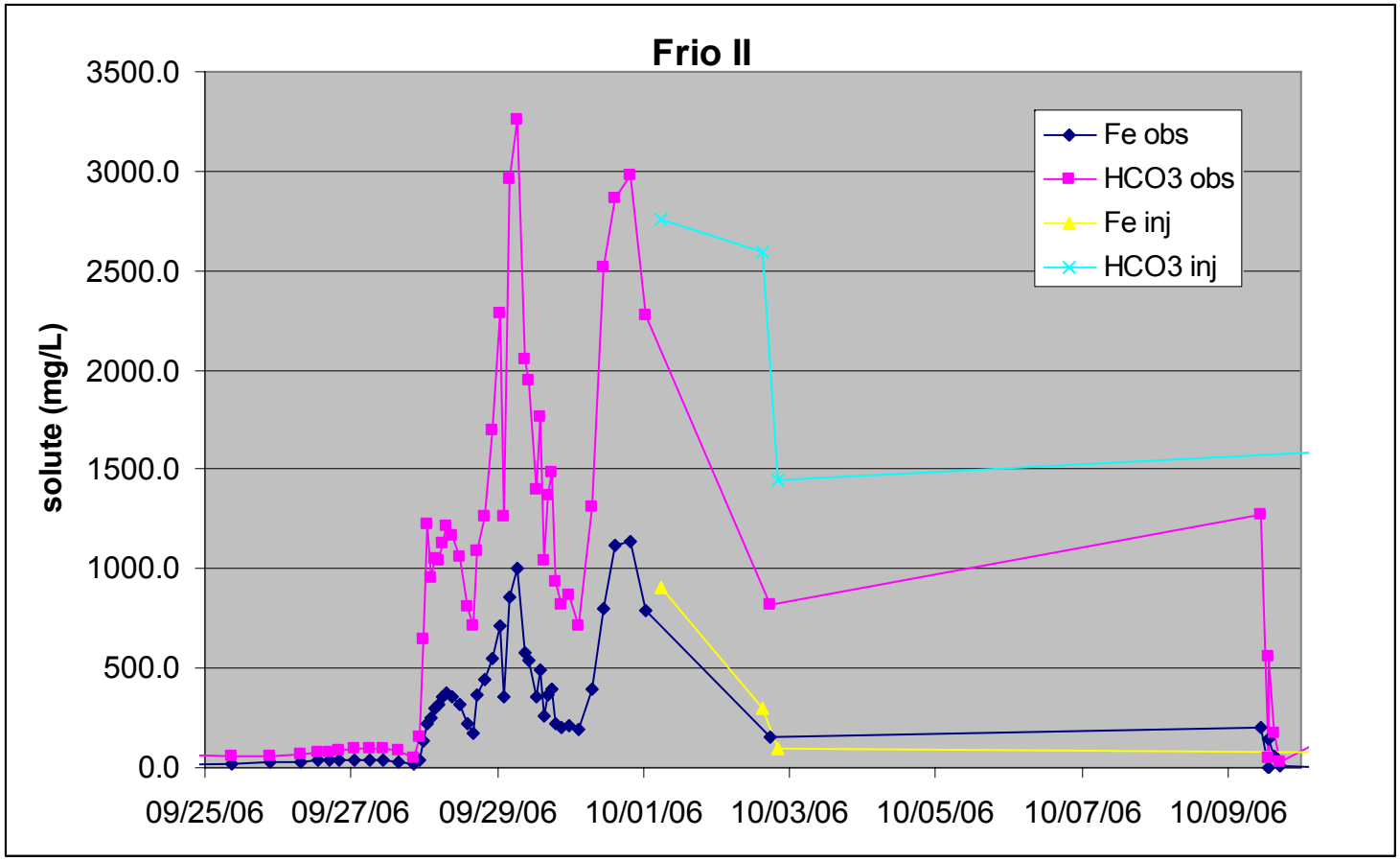
Frio II Timeline



Frio II Timeline
Evidence of Breakthrough of CO_2 to Observation well

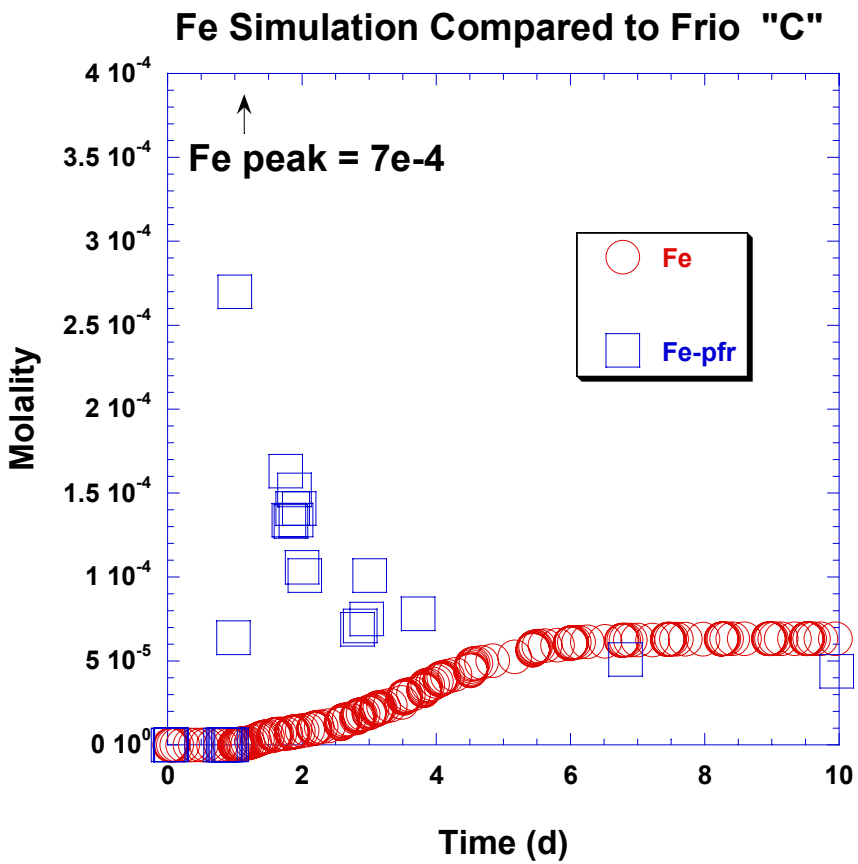


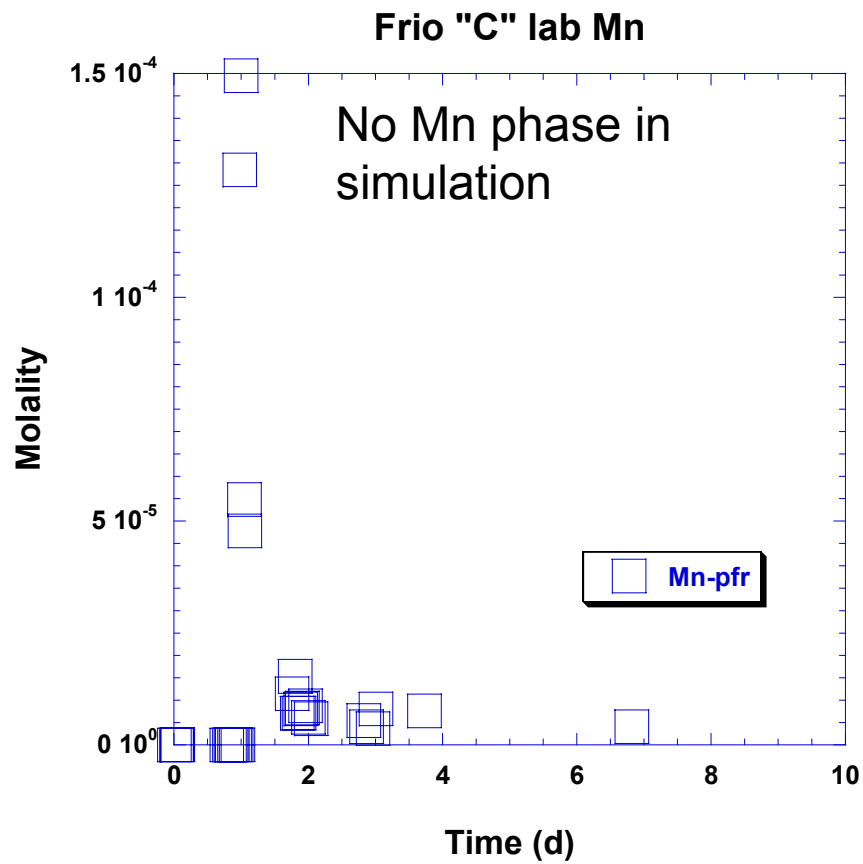
Geochemical Evidence of CO_2-Rock Interaction



Yousif Kharaka, USGS

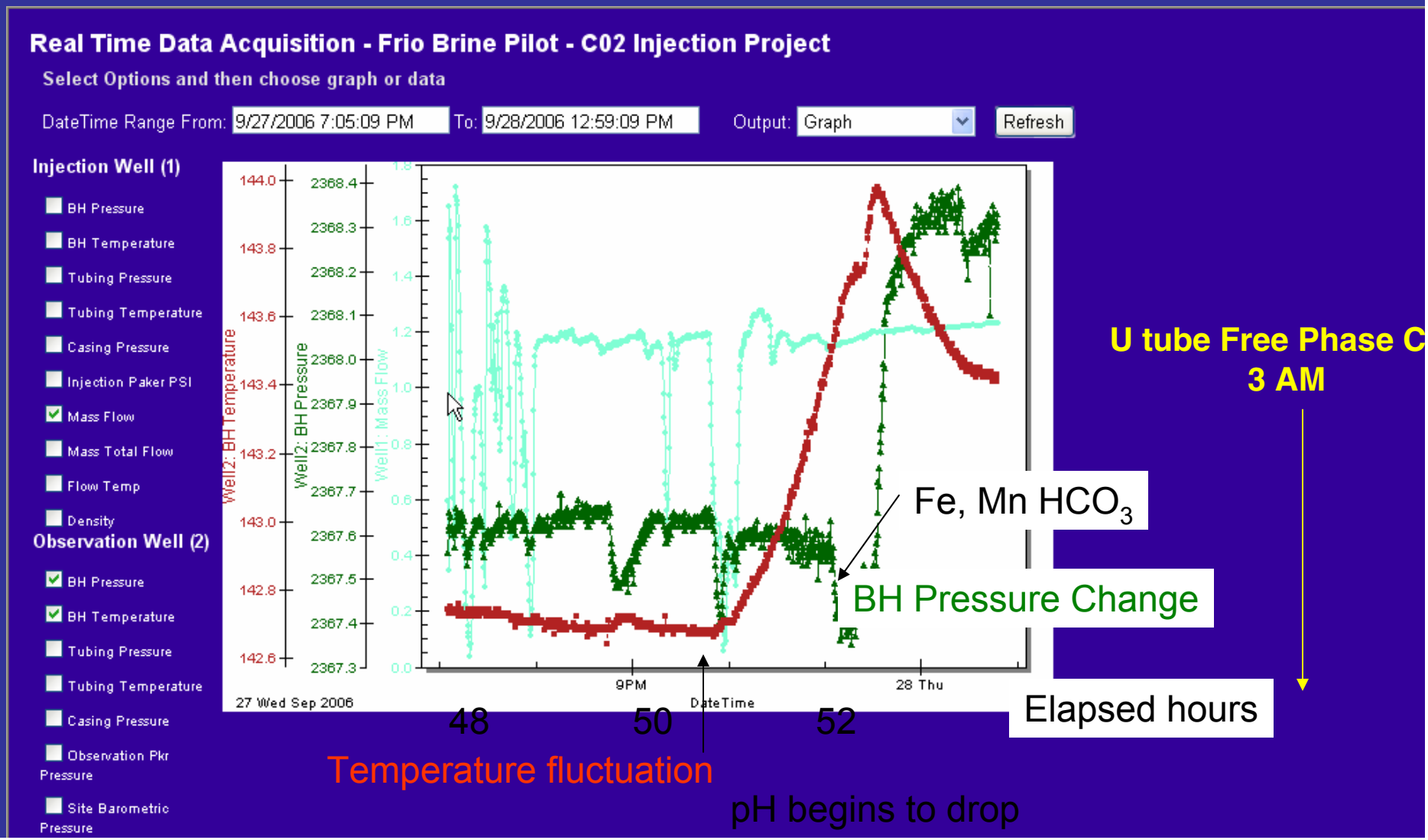
Geochemical Simulation vs. Lab data



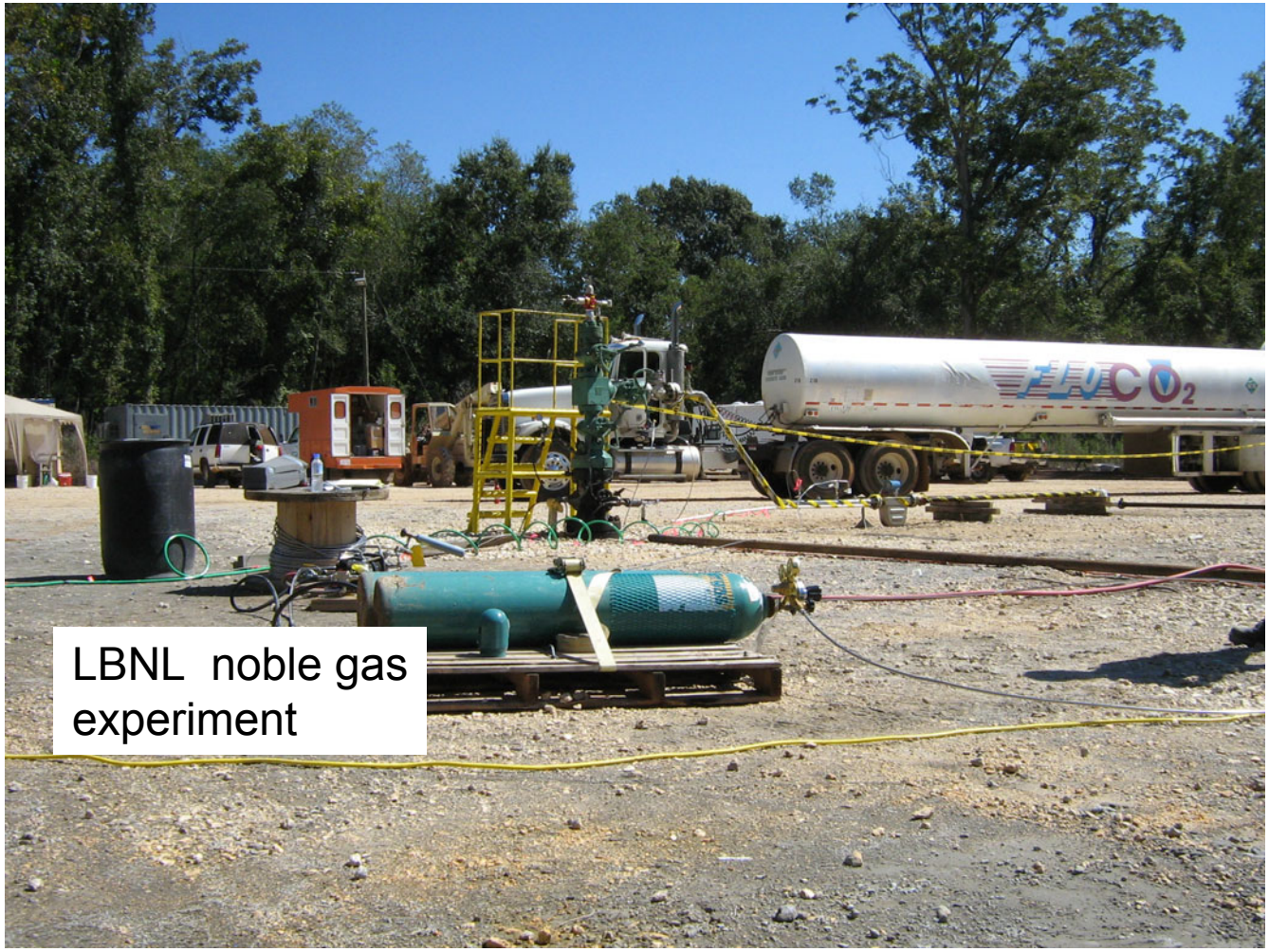


Kevin Knauss, LLNL

Rapid Breakthrough



FRIO II CD_4 Tracer Injection Experiment



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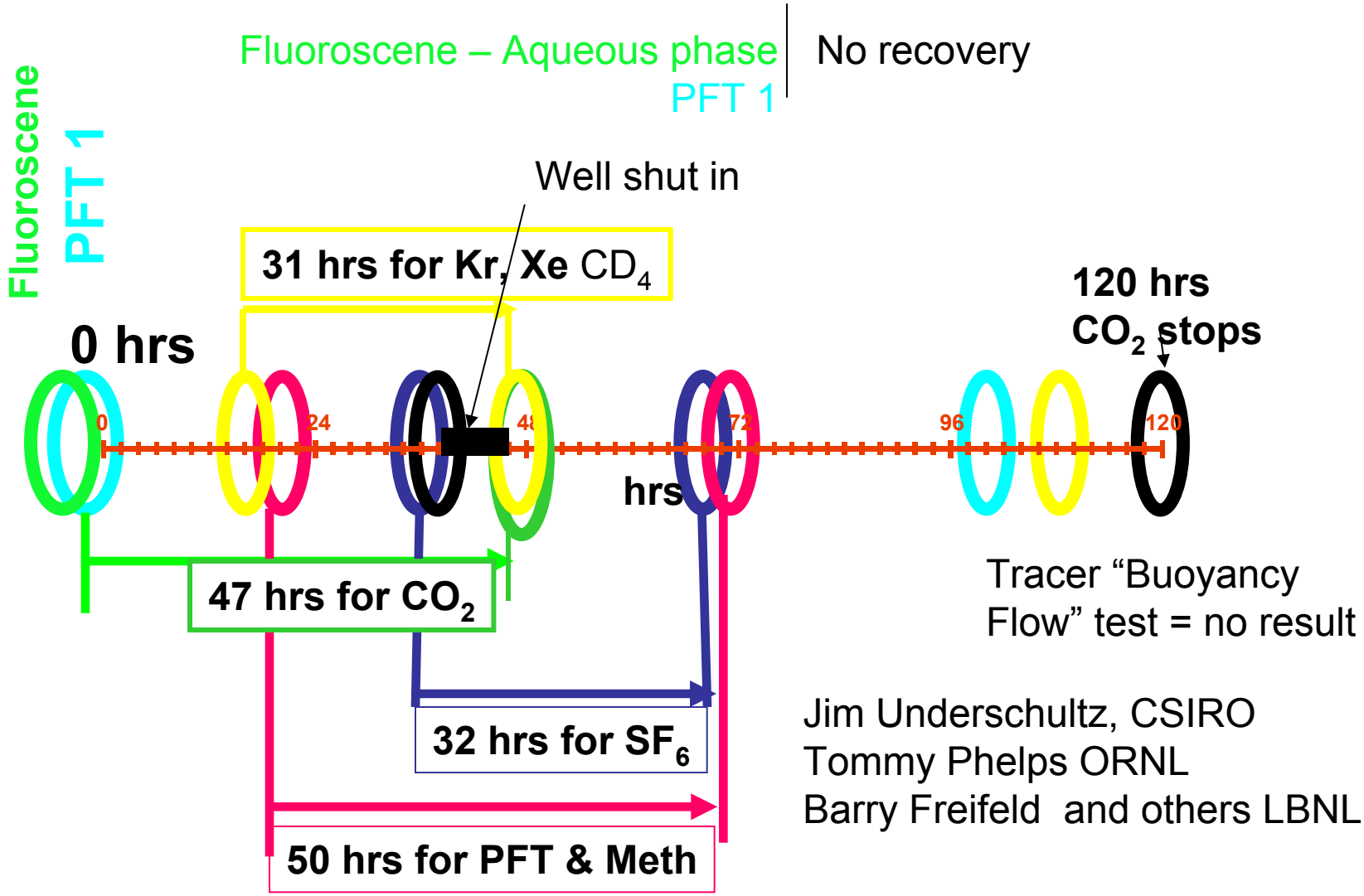
[1]CSIRO Petroleum, [2]Geoscience Australia, [3]Alberta Research Council.

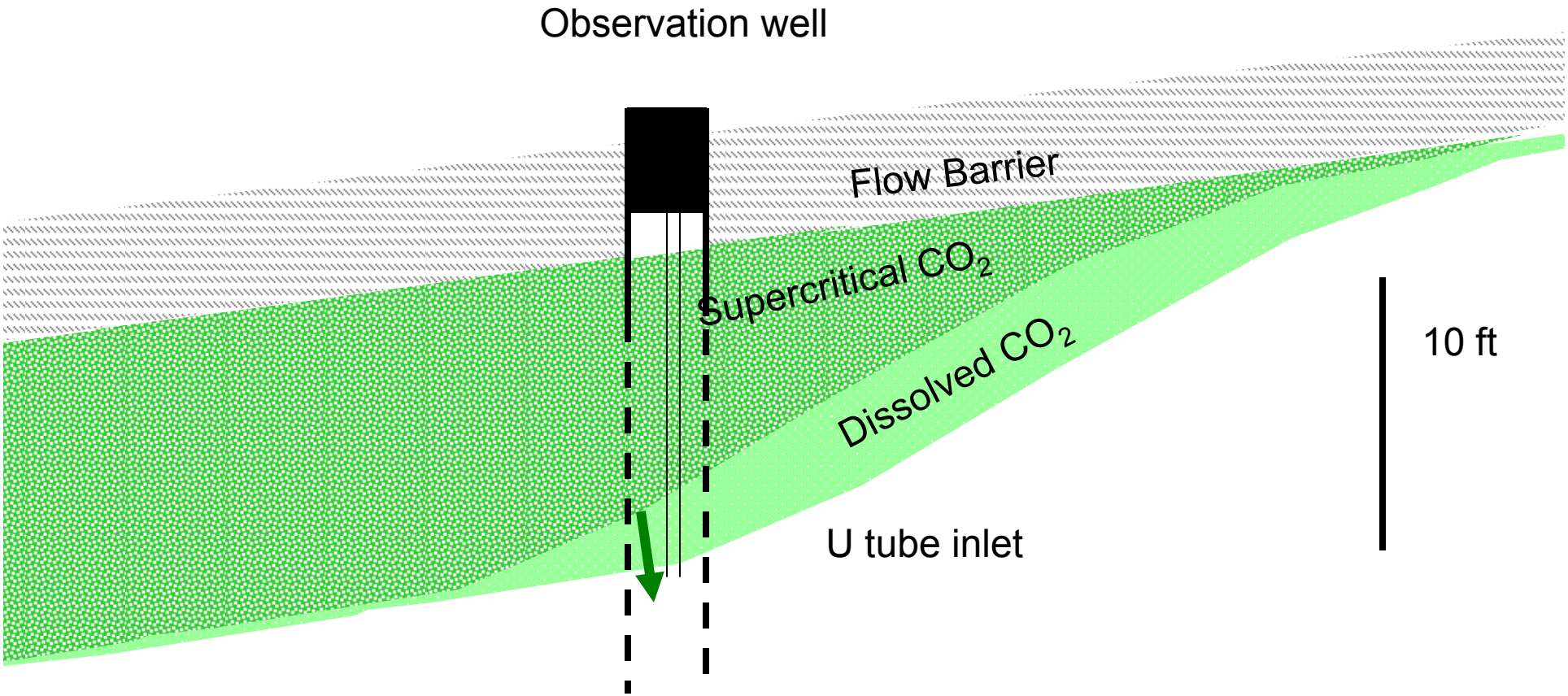
Frio II Tracer Timeline (Provisional Data) - Evidence of Complex Flow Processes



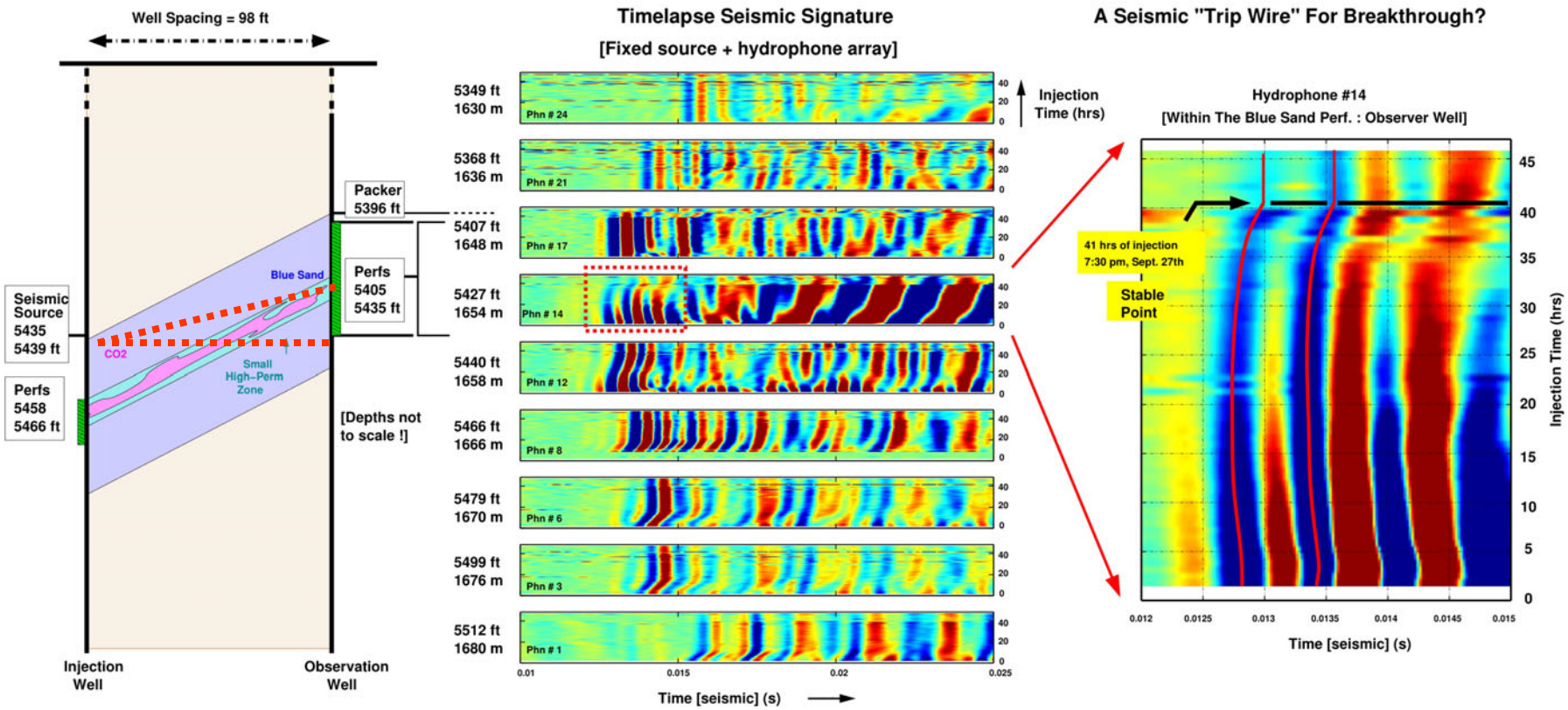
Tracer "Buoyancy Flow" test = no result

Jim Underschultz, CSIRO
Tommy Phelps ORNL
Barry Freifeld and others LBNL

Breakthrough – Fluid Change in Well-bore as a response to Plume Downbuilding?



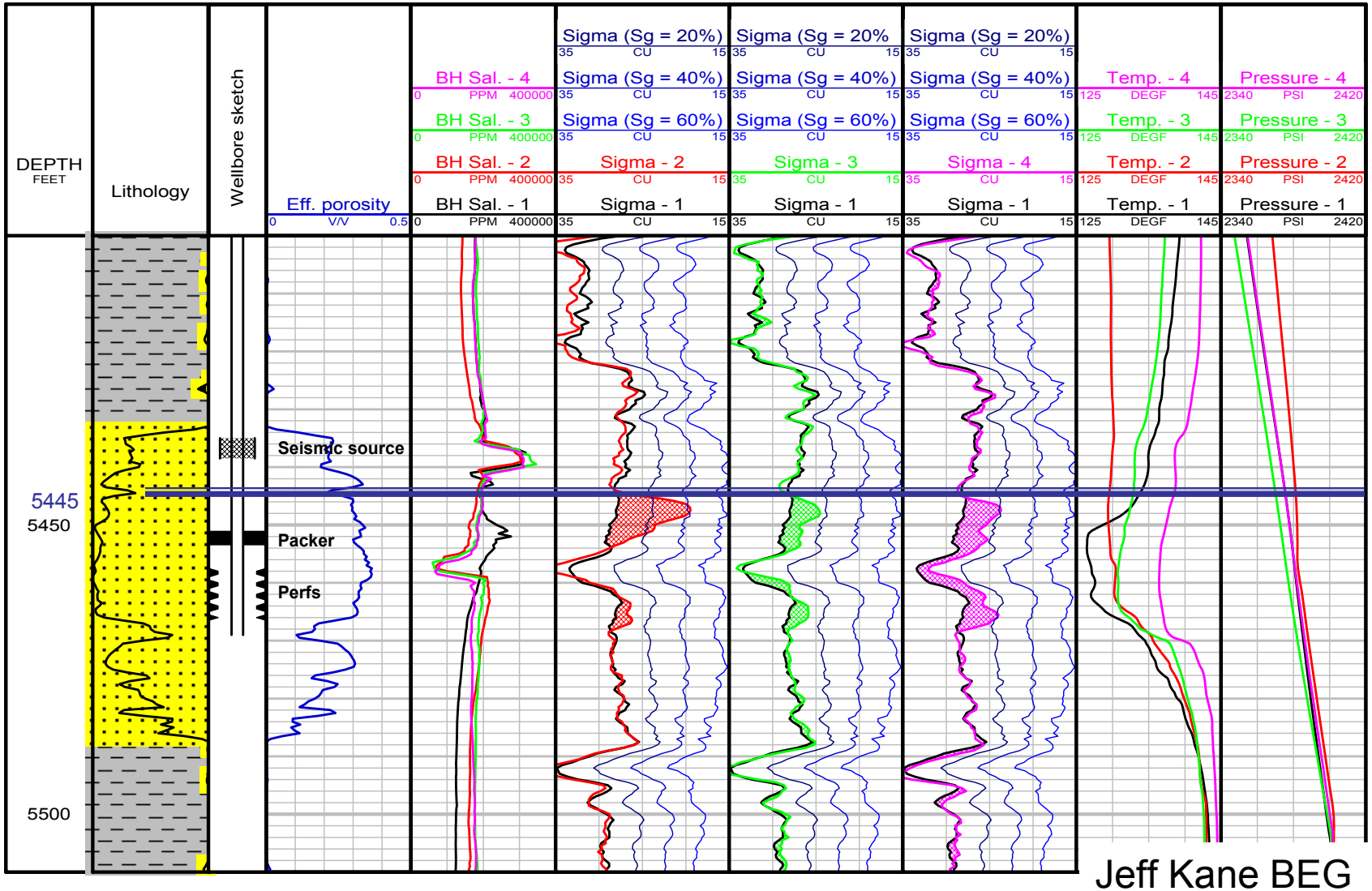
Frio-II CASSM: Change in first arrival indicates fluid substitution along ray-path



T Daley LBNL J.B. Ajo-Franklin MIT

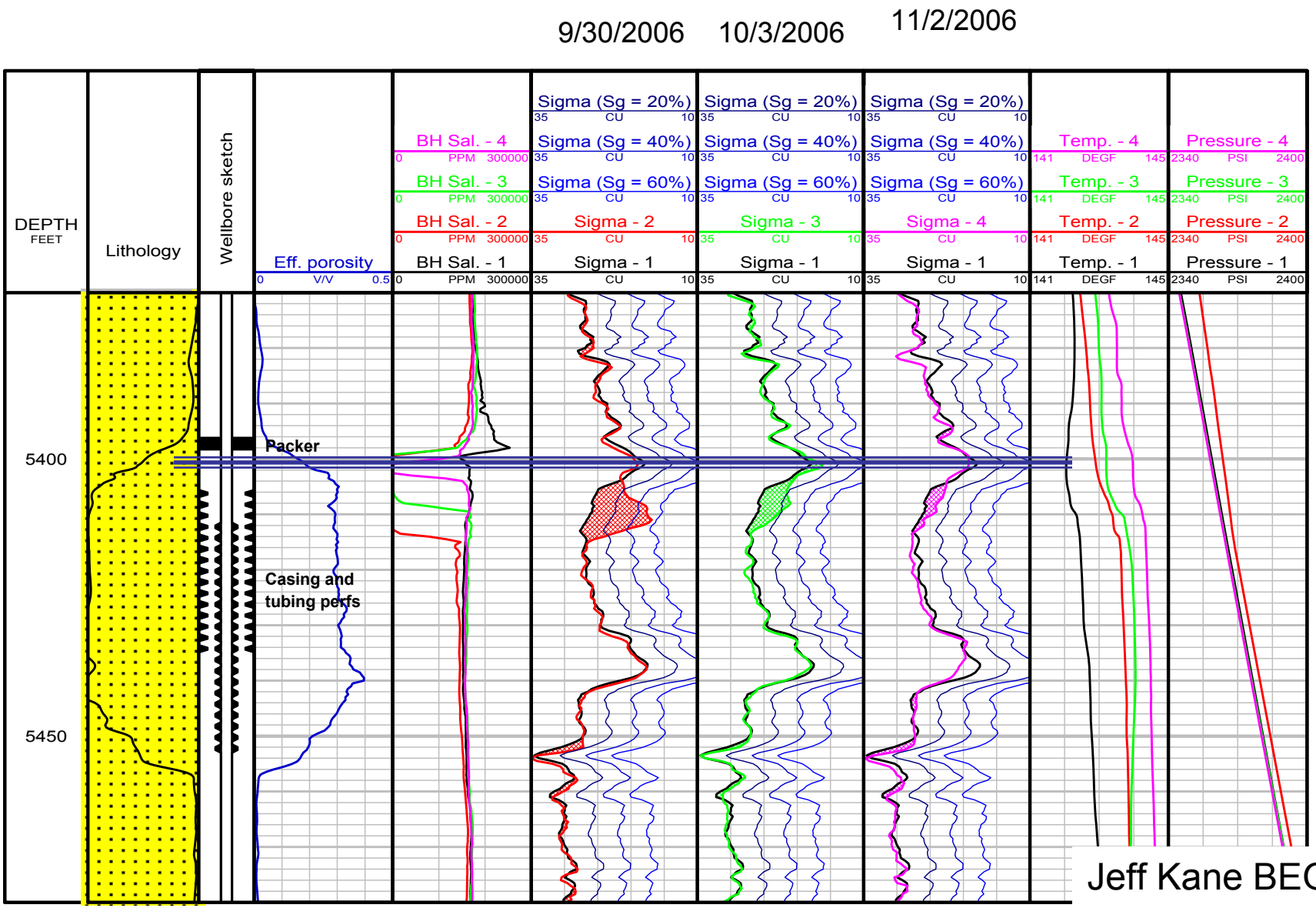
Change in CO_2 Saturation At Injection Well Over Time

9/30/2006 10/3/2006 11/2/2006



Jeff Kane BEG

Change in CO_2 Saturation At Observation Well Over Time



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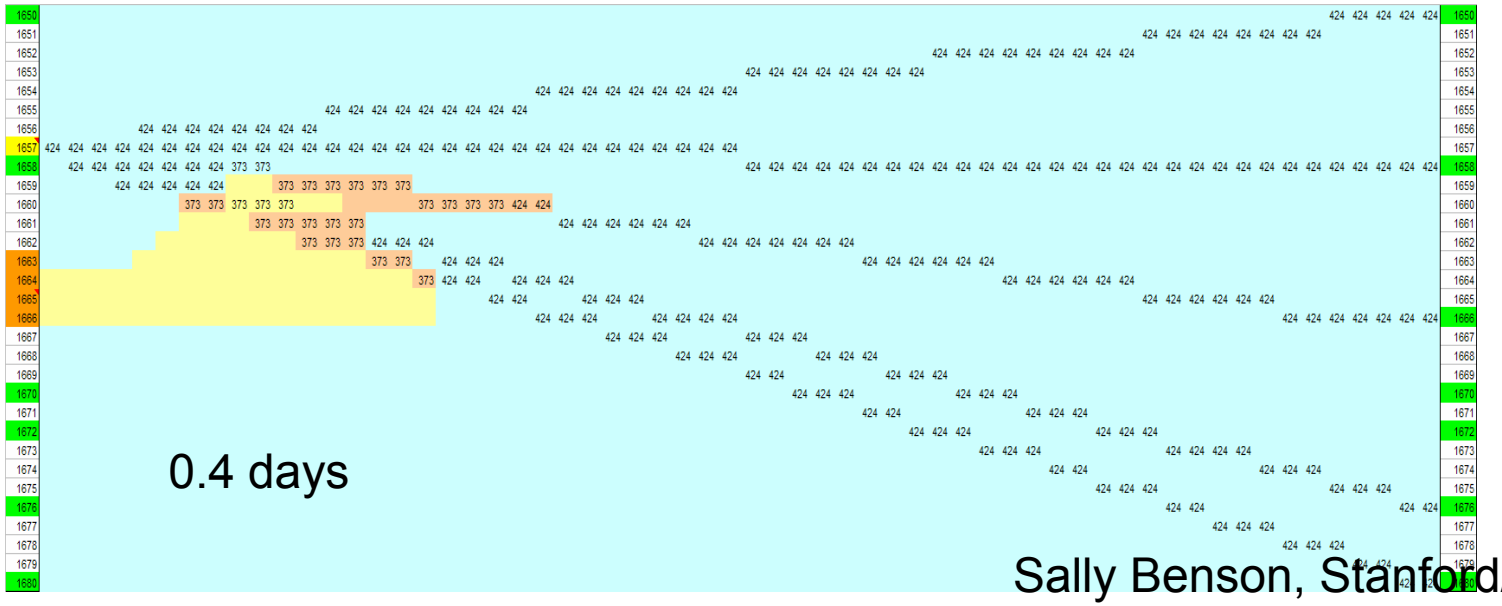
Estimating Flow Geometry from Travel-Time Delay



Sally Benson, Stanford/ LBNL

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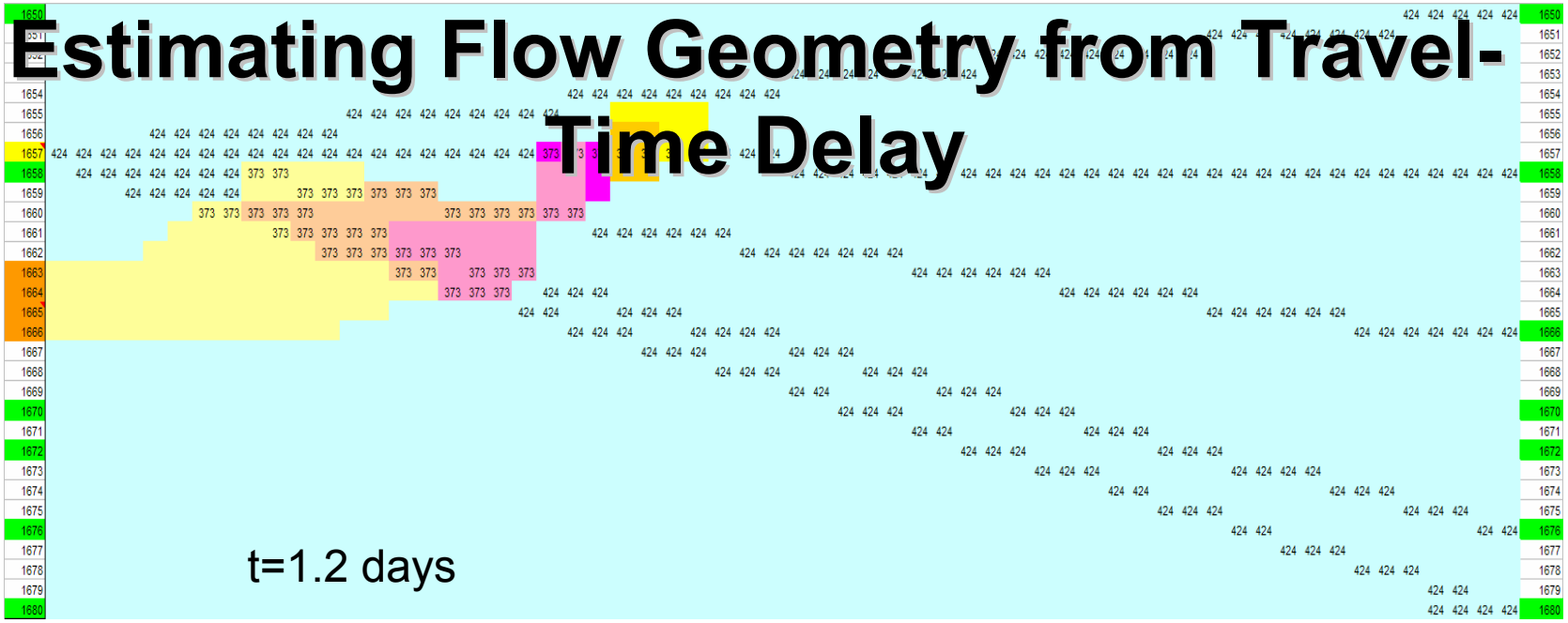

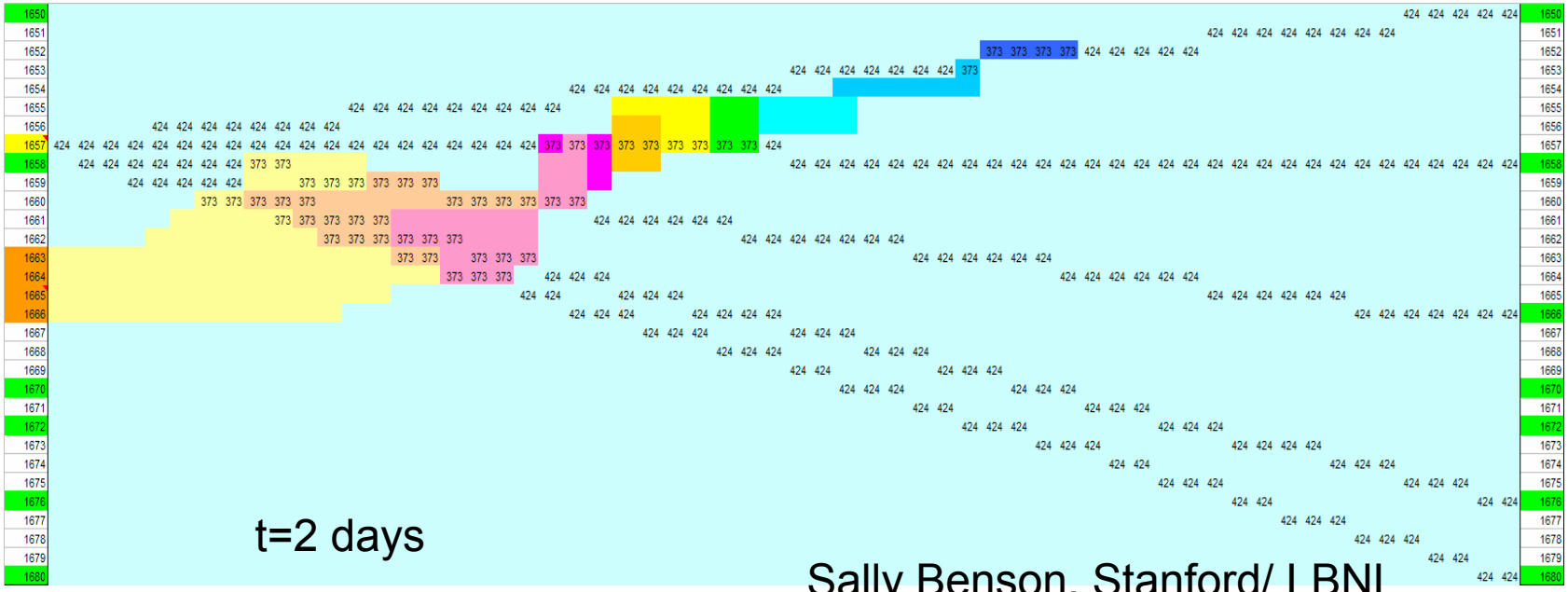

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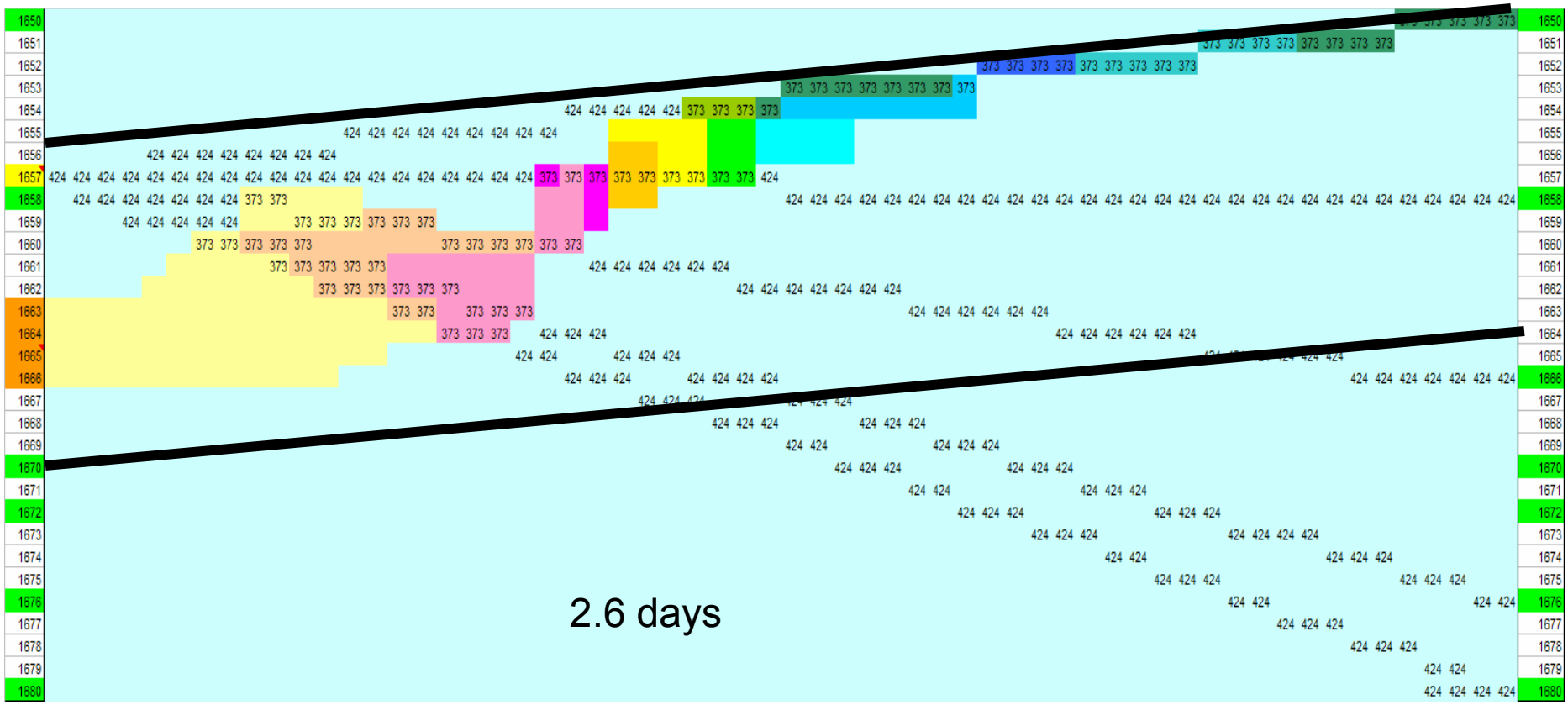

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30 m

Conclusions

- Frio II investigated heterogeneous and a thick high permeability (Average >4 Darcy) sandstone, 30 ft thick, slow injection rate 50T/day
- CO_2 rose rapidly and moved preferentially through uppermost high permeability zones
  - Detect with new seismic tool
  - Observed decreased pH, dissolved Fe, Mn
  - Plume downbuilding
- Significance to sweep efficiency, capacity, and trapping mechanisms ??